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REPORT

The improved display of 625-line television pictures

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Summary

Conventional television, shown on the 625/50 standard with 2:1 interlacing of adjacent fields suffers several minor defects which become much more visible on large, bright displays. Large-area flicker and interline (interlace) twitter are easily seen, and line crawl, resulting from interlace, occassionally causes the picture to appear to be composed of only 312½ lines. All these effects can be eliminated or reduced by displaying the received signal on a higher standard, such as 625/100 with 2:1 interlace or with sequential picture lines (1:1).

This Report describes the defects of 625/50, 2:1 displays and some of the ways in which they can be rendered less visible. Experimental monochrome results show that conversions to 625/100 with 2:1 interlace, 1250/100, 2:1 and 625/100, 1:1 all offer considerable prospects for improvement although the requirements of motion portrayal and vertical definition present conflicting requirements for the interpolation process. Less success was had with experiments using a 1250/100, 4:1 interlaced scanning structure, since it was found to be excessively prone to line crawl.

Further work is planned to develop an adaptive interpolator controlled by a motion detector and to provide for experiments in colour.

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THE IMPROVED DISPLAY OF 625-LINE TELEVISION PICTURES

A. Roberts, B.Eng.

1. Introduction

In 1964 when the first regular television transmissions on the 625-line standard were made in the UK, domestic receivers were monochrome, with fairly small and relatively dim pictures; any defects of the display scanning structure were accepted as inevitable. Twenty years later, pictures are bigger and brighter with the future possibility of screen sizes increasing still further. The defects are already more apparent and will become more so in the future. Large-area brightness flicker, and interline twitter due to the 50 fields per sec interlaced structure can be quite distracting.

This Report describes methods of removing or reducing these defects by signal processing in the receiver, based upon combinations of increased line and field scanning rates and sequential display of picture lines. Any domestic 'hi-fi' television receiver operating in such a way when receiving conventional 625-line, 50-field broadcast signals, may have to be judged in comparison with its picture quality when receiving signals from wideband cable distribution, high-definition video cassettes, video discs, or possibly a true high definition satellite broadcasting system. An experimental High-Definition Television (HDTV) broadcasting system has already been seen.[1] Whether or not a high field rate display derived from 625/50 can compete with such systems is uncertain, but it is shown here that the improvements gained over the conventional 625/50 display are significant and worthwhile.

The work described is incomplete, in that further work is required to develop the necessary equipment to portray motion adequately and preserve or improve vertical definition simultaneously, but initial results are encouraging.

2. Defects of the conventionally displayed 625/50 standard

2.1. General characteristics

A conventional cathode ray tube display, together with the eye, can be described as a lowpass filter in two dimensions. Its function is to recreate a smooth flow of information from a set of regularly occurring samples derived from the original scene by the scanning process. If the sampling rates were made sufficiently high, all lowpass filtering would be done by the eye, but this would entail an extravagant use of transmission bandwidth. Thus the display is ideally required to act as a lowpass filter, relieving the eye of the job.

There are four main defects of a conventional display which are described below.

2.2. Large-area flicker

Large-area flicker occurs at the 50 Hz field frequency. It is perceived primarily in peripheral vision and is thus aggravated by any increase in the angle subtended at the eye by the display. It is also a function of display brightness, due to the brightness/response-time relationship connecting temporal integration in the eye with perceived brightness[2,3].

2.3. Interline twitter

Interline twitter occurs at the 25 Hz picture frequency, and is caused by the conventional interlaced display of alternate fields. It arises in areas of high-amplitude vertical detail with frequencies approaching the Nyquist limit of 312½ cycles per picture height, half the vertical sampling rate of 625 lines per picture. In the limit, at 312½ cycles per picture height, the picture is composed of alternate light and dark fields. The effect is aggravated by increased viewing angle and is also a function of display contrast, due to a perception mechanism similar to the brightness/response-time relationship mentioned above.

2.4. Line crawl

Line crawl also results from the interlaced scanning process. It is most readily seen when moving vertical detail in the scene forces the eye to scan the display at or near a critical rate of 11.5 seconds per picture height, or at higher harmonic rates such as 5.75 seconds per picture height. The crawling structure is that of a field of 312½ lines and is thus more visible than that of a picture of 625 lines. Obviously, there is also a consequential loss of vertical resolution. It is unfortunate that the speed of vertical movement of detail in pictures, particularly with rolling captions, is often about the same as line crawl.

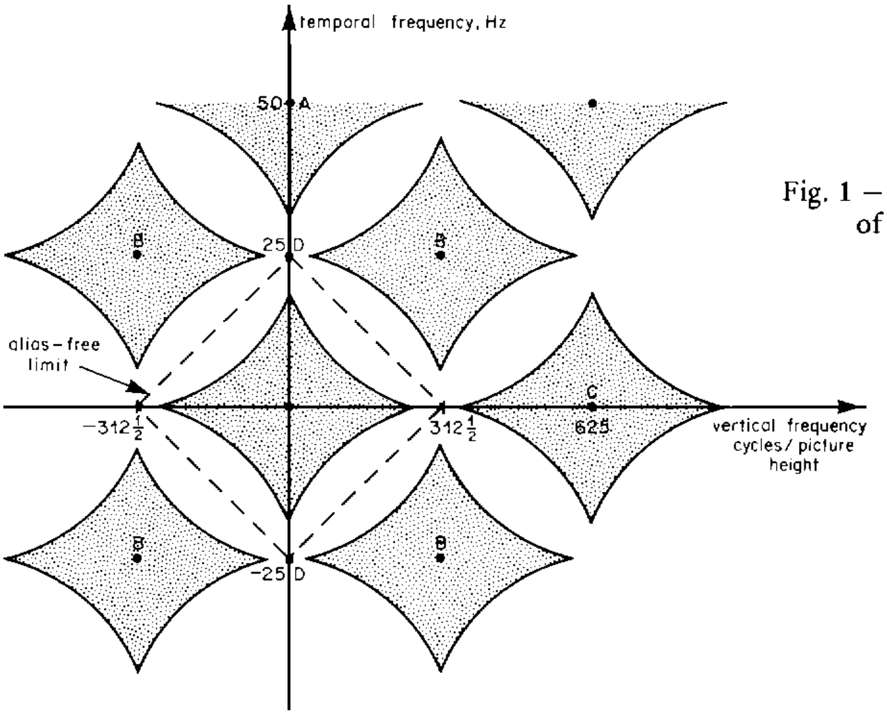

Fig. 1 — The vertical-temporal spectrum of a conventionally scanned image.

2.5. Static line structure

The lines of a 625-line picture can be seen individually on a low brightness display, or on a high-quality picture monitor. At normal brightness on a domestic receiver, they may not be visible due to the larger spot size. If the spot size is reduced in order to obtain a 'higher resolution' display, the structure is readily seen. Again, any increase in the viewing angle will aggravate the line-structure visibility.

2.6. Picture source defects

An increase in the viewing angle also aggravates any defects in the picture source material. Noise, film grain, cross-colour, cross-luminance, lack of sharpness, edge effects and poor film steadiness all look worse on a large display. A limited series of subjective tests was carried out to quantify some of these effects, and the results are given later in this Report.

3. Possible solutions to the problems

3.1. The basic approach to the problem

The impairments listed in Section 2 relate to the scanning structure and are all defects of the conventional display device. If we consider the two-dimensional vertical-temporal frequency plane for a scanned image as shown in Fig. 1, then the display is required to reject all the higher order spectra created by the scanning process. Failure to do this in certain spectral areas results in the characteristic impairments for those areas. The figure shows a typical non-overlapping spectrum of a scanned image.

Failure to reject in the region centred

on A — results in large-area flicker,

on B — results in line crawl

on C — results in static line structure

and on D — results in inter-line twitter.

Now, from sampling theory we know that the 625/50 scanning structure can support only a limited area such as that bounded by the locus shown as a pecked line in Fig. 1. Furthermore, however good the display device is at rejecting higher order spectra, it cannot reject them if the repeated spectra overlap; such overlapping spectra occur with pictures containing excessive vertical and/or temporal detail.

To ensure no overlap, therefore, the source signal must be prefiltered before scanning. Failure to do this results in the characteristic impairments of temporal aliasing (rotation reversal) and spatial aliasing (coarse stationary patterns in fine detail).

Some filtering occurs in typical sources by means of the film-camera shutter or the temporal integration of the electronic camera coupled with the effect of the size of the scanning spot. However, this is nowhere near enough to restrict the signal spectrum to the alias-free area of Fig.1 in the temporal direction.

In practice, it is rare for television sources to produce coarse stationary patterns (as opposed to twitter) and the eye seems to tolerate temporal aliasing. Thus the defects of the conventional system arise mainly from failure of the display to reject the higher order spectra. The work described in this Report has concentrated on improving the display and particular attention has been given to the preservation and possible improvement of vertical definition, together with the satisfactory portrayal of motion.

Several new display structures have been considered, their parameters having been drawn from the following list:-

– Interlace:	1:1 (sequential) 2:1 4:1
– Line rate:	625 lines/picture 1250 lines/picture
– Field frequency:	50 Hz 100 Hz

3.2. Discussion of the properties of the new standards

3.2.1. The effects of interlace

Interlace primarily affects inter-line twitter and line crawl. With a 1:1 (sequential) structure, twitter can be eliminated since all fields are complete pictures. With a 2:1 structure, twitter can be reduced if 1250 lines are used, to a degree dependent upon the interpolation chosen, or if the field rate is raised to 100 Hz. With a 4:1 structure, twitter can be improved a little if 1250 lines are used and the field rate is raised to 100 Hz.

Line crawl is eliminated by using a 1:1 structure, or virtually eliminated by using a 2:1 structure with 1250 lines because the crawling structure has 625 lines which are barely perceptible when crawling. Structures with 4:1 interlace crawl badly because the crawling structure has 312½ or 625 lines.

3.2.2. The effects of line rate

Line rate primarily affects structure visibility, and has a lesser effect on line crawl and twitter.

With 1250 lines, structure visibility is greatly reduced except for 4:1 interlaced structures which are dominated by line crawl. However, the 'restful' appearance of the 625-line, 1:1 structure is almost as pleasing as the low visibility of lines with the 1250, 2:1 structure.

Similarly, line crawl is virtually eliminated by the 1250-line, 2:1 structure, since it crawls with a 625-line format. As mentioned above, line crawl is not improved by 1250-line, 4:1 structures but is eliminated by the 625-line, 1:1 structure.

The 625-line, 1:1 structure eliminates twitter completely and the 1250-line, 2:1 structure reduces it considerably, but 1250-line, 4:1 structures have little effect.

3.2.3. The effect of field rate

The primary effect of field rate is on large-area flicker; at 100 Hz it is eliminated, whatever other parameters the structure has. Kraus[4] reported that the elimination threshold occurs at 75 Hz on modern, bright CRT displays.

4. The new display structures

4.1. General comments

A standards converter was built to assess display structures and interpolation algorithms. Initially full-sized pictures were displayed on a modified monitor, but later, in order to display adequately the 1250-line structures and those requiring a 62,500 Hz line-scanning frequency, the apparatus was modified to display one quarter of the picture, half the height and width of the input picture. This 'enlarged' picture, when seen on a 48 cm diagonal picture monitor, was of approximately the correct size for a large-screen domestic 'display-of-the-future' with a 1 m diagonal. As an added advantage, all the line frequencies and consequently the video bandwidths were halved, since only half the lines of a full picture were displayed during each field period. The scanning rates and interlace factors available are summarised in Table 1.

Enlarged pictures were used for all the subjective assessments, on a suitably modified picture monitor which was thus never required actually to show more than 625 lines for any structure.

For practical reasons connected with the design of the equipment, the output structures were phase-locked to the input standard, and the monitor driven with a 625/100, 2:1 interlaced

TABLE I

Lines per picture	Fields per second	Interlace factor	Line-Scan frequency in kHz
625	50	2:1	15.6
1250	50	2:1	31.2
625	50	1:1	31.2
625	100	2+2:1	31.2
625	100	2:1	31.2
1250	100	4:1	31.2
625	100	1:1	62.5
1250	100	2:1	62.5

raster. All the output structures were displayed on this raster, with lines and fields blanked when not required. For some of the structures a vertical perturbation was needed to effect a true interlace.

Subjective tests were carried out using a variety of test material to evaluate the performance of the structures listed in Table 1. The results are given in Section 5 where it can be seen that the comments in this section on the performance of structures and algorithms were largely confirmed by the subjective tests. For clarity and to avoid repetition, consideration of the order of preference for the new structures is deferred until Section 5.

In all the Figures in this section, an 0 represents a line of the input 625/50, 2:1 standard and an X represents a line of the output structure. Time progresses to the right, vertical position is represented on the vertical axis, and the scanning lines are perpendicular to the paper; thus a vertical array of lines represents one field.

Two general-purpose interpolation algorithms were derived and used for most of the structures. It will become clear that one algorithm is better for the portrayal of spatial detail in pictures while the other is suited to motion. They will be described as applied to a 625/100, 2:1 structure, but the description applies to most of the other scanning structures as well.

The detail algorithm is shown in Fig. 2. It can be seen that each line of the output structure is derived wholly from the temporally nearest line which is spatially accurate in the vertical direction. In this way no vertical detail is lost, and since the phase of the even/odd field sequence of the input signal is preserved, the twitter frequency is raised to 50 Hz. Unfortunately this results in a cyclic reversal in the flow of information, giving rise to motion judder. As can be seen from Fig. 2, if the input fields are monotonically labelled 1,2,3,4,5, then the output sequence of fields is 1,2,1,2,3,4,3,4,5. The reversal in the sequence at 2,1 and 4,3 causes unacceptable judder in motion portrayal.

It is worth noting, however, that this effect is apparent only when the source material is composed of fields each scanning the scene separately, such as those from television cameras or electronic pattern-generators. With a film source scanned at 25 frames per second, where two successive fields are from the same picture, motion portrayal can be as good as in the original film.

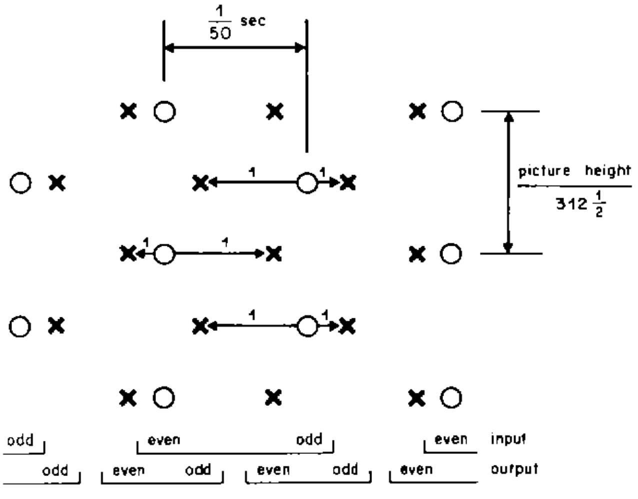

Fig. 2 — Detail algorithm.

There are two phase relationships of the detail algorithm. In the phase shown in Fig. 2, the fields of a picture are repeated (even-odd); in the other the fields are repeated in the other order (odd-even). Both are equally valid, in that spatial accuracy is preserved. With a film source which is 'correctly' frame-phased, i.e. an even field and the following odd field are both derived from the same film frame, the phase shown does not harm motion portrayal since each frame is simply shown twice in four fields, while the other phase introduces additional judder. For 'wrongly' frame-phased film the opposite is true.

In the algorithm suited to motion in pictures, shown in Fig. 3, each input field is again used twice, its odd or even field identity being lost. Output fields are obtained with a line-delay interpolator using appropriately weighted contributions from the temporally nearest input field; weighting factors of ½ and 1 are shown in Fig. 3. The interpolated fields, while being correctly sited vertically, have a vertical frequency-characteristic which has a zero-response at 156¼ cycles per picture height because of averaging over two lines. This is visible as a vertical softening of the picture accompanied by a 25 Hz twitter in areas of the picture containing information at or near 156¼ cycles per picture height, since alternate output field-pairs are obtained by line-averaging. Interline twitter at 312½ cycles per picture height is unaffected and remains at 25 Hz; since each output picture is derived entirely from one input field.

An alternative motion algorithm is shown in Fig. 4 in which all lines are treated equally, being weighted sums (weighting factors ¼ and ¾) of the temporally nearest lines. Each field has a vertical frequency response which has a 6 dB dip at 156¼ cycles per picture height, resulting in a subjective softening. Twitter at 312½ cycles per picture height is again unaffected. Unfortunately, as can be seen by comparing figures 2 and 4, this algorithm is slightly differently phased from the detail algorithm; a small vertical shift would occur on switching between the two, and so it cannot be considered for any movement adaptive system.

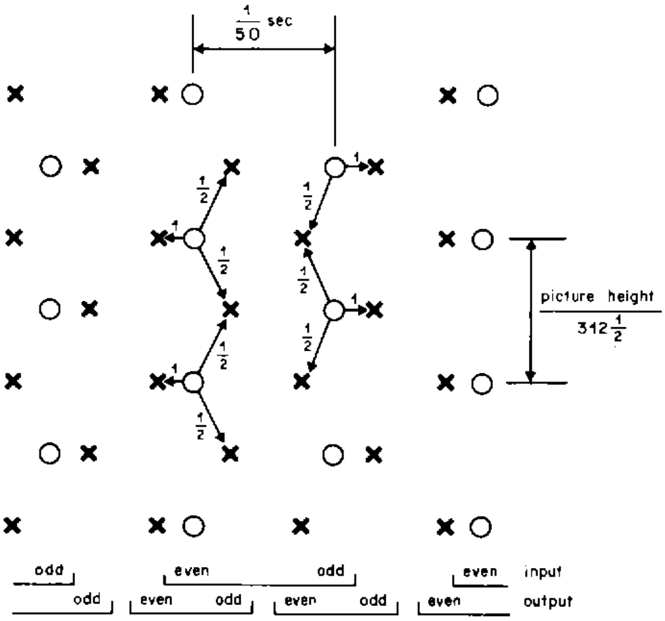

Fig. 3 – Motion algorithm.

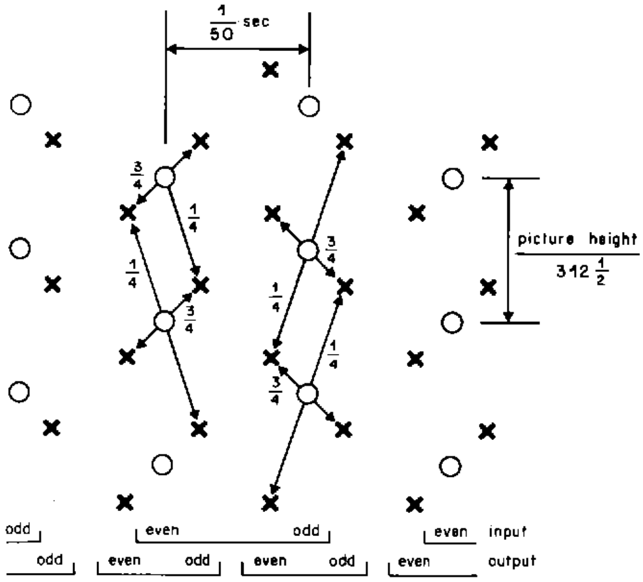

Fig. 4 – Modified motion algorithm.

It was hoped that a compromise algorithm might be found having the benefits of the detail and motion algorithms but without their disadvantages. Many algorithms were devised, some were tested, others rejected before testing, but no satisfactory algorithm could be found. Despite the failure to find a compromise, important conclusions were drawn:-

– Output fields must be presented in the same sequence in which they occur at 625/50 to avoid movement judder.

– Interpolation between two or more fields produces unacceptable blurring during motion.

– Simple interpolation using a one-line delay produces an unacceptable softening of stationary pictures but is satisfactory for moving pictures.

– If interpolation is used, all fields and lines should, if possible, be subjected to the same

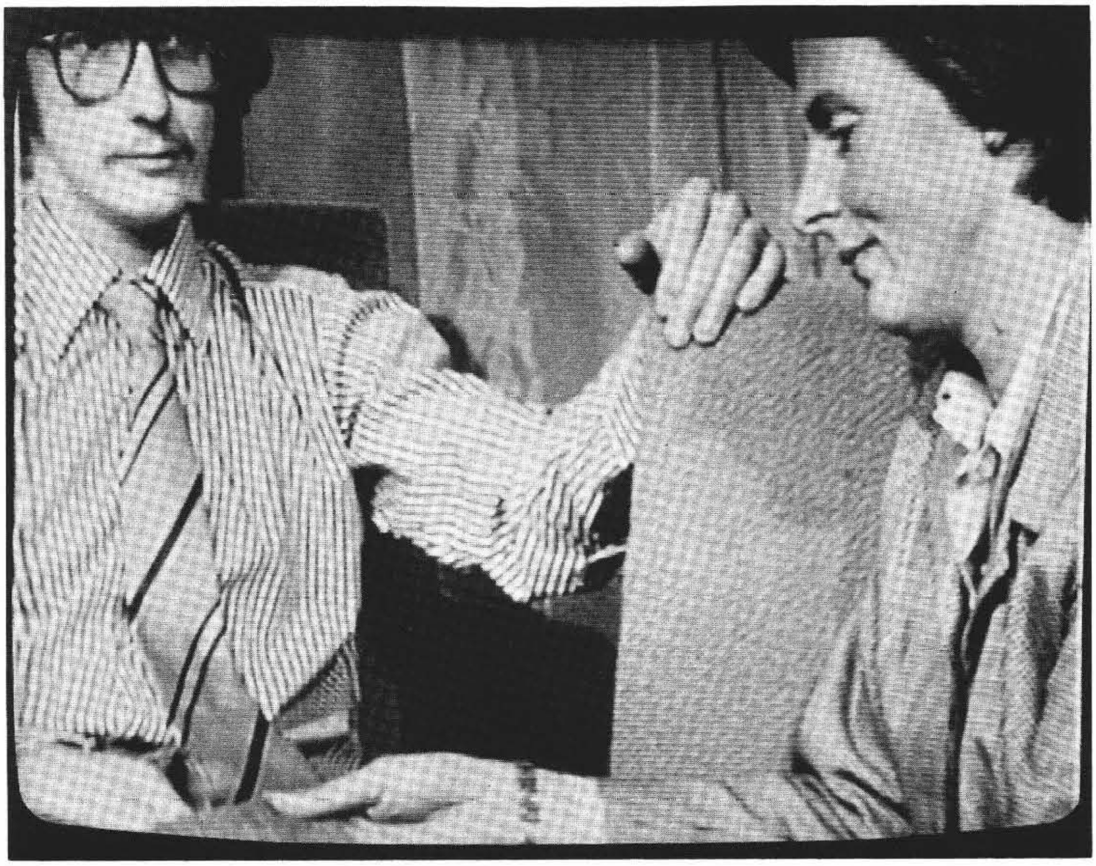

Fig. 5 – 'Young Couple' slide enlarged, showing 'line-quadding' on a 1250/100 4:1 structure.

processing to avoid inter-line twitter in softened areas.

In addition to increased scanning rates, perturbation of the field-scanning currents in the deflection circuits of the picture monitor is required for several of the structures; typical waveforms are shown in the relevant structure diagrams. Two picture monitors were modified to run at 31,250 Hz line frequency and 100 Hz field scan frequency; both were then perturbed to achieve all the structures. Some difficulty was experienced with the 4:1 structures which required a scanning coil current perturbation at 25 Hz; one monitor responded non-linearly to the perturbation signal and a complex equaliser was used to correct the distortion. Neither monitor performed very well with 4:1 structures; interlace could usually be achieved accurately over only 20% of the picture, while other areas showed four-line 'quadding' revealing a 312½ line structure within the 1250-line structure. This is shown in Fig. 5. If scanning circuits were designed with perturbation in mind, however, this problem could easily be overcome. From measurements made during the work on perturbation it is estimated that an error of ± 1/20th picture line pitch is about the threshold of perception for a lack of uniform interlace.

4.2. 625/100,2:1 interlaced

The scanning structure is obtained by simultaneously doubling the line and field scanning rates to 31,250 Hz and 100 Hz respectively, and the video bandwidth to 11 MHz.

Large area flicker is eliminated. The speed of line crawl is doubled, its lowest rate being 5.75 seconds per picture height but a 312½ line structure is seen when crawl does occur. Twitter can be eliminated by the interpolation process but structure visibility is not reduced.

The structure and algorithms for 625/100 2:1 are shown in Fig. 6. The detail algorithm (D in Fig. 6*) eliminates twitter simply by raising its temporal frequency to 50 Hz, at which it can be seen only when provoked by small sudden movements of the eye; in practice twitter is seldom seen. Motion portrayal by the detail algorithm is very poor; judder is caused by the cyclic reversal in the flow of information from input to output. The motion algorithm (M in Fig. 6) preserves twitter at 312½ cycles per picture height and 25 Hz, and introduces a flickering frequency-characteristic loss at 156¼ cycles per picture height, but motion portrayal is good.

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* For clarity in Figure 6 and subsequent figures the weighting factors have been omitted, they are chosen on the basis of distance.

A defect of the motion algorithm is that sharp vertical edges moving at low horizontal speeds of around 10 seconds per picture width break up into 'combing'; all the odd fields are bodily displaced from the even fields; this is shown in Fig. 7. The same defects can be seen on film shown conventionally on 625/50 television but at lower speeds. At higher speeds the 'combing' effect is replaced by 'fringing', where the edge of a moving object is seen as two distinctly separate edges; this is similar to normal judder as seen on film shown on 625/50 television. It is thought that the eye converts the temporal error resulting from the repeated images into a spatial one. However, for all normal picture sources the effect is small and not easily identified.

4.3. 625/100, 1:1 interlaced (sequential)

This structure requires a doubling of the field scanning frequency to 100 Hz and a simultaneous quadrupling of the line scanning frequency and the video bandwidth to 62,500 Hz and 22 MHz respectively.

Large area flicker is eliminated and structure visibility may be reduced through the restful appearance of the sequential raster. Line crawl is eliminated; twitter may also be eliminated by careful choice of the interpolation process.

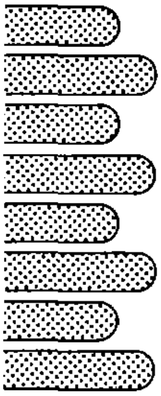


Fig. 7 – Representation of a black edge moving horizontally, displaying 'combing'

The structure and algorithms for 625/50, 1:1 are shown in Fig. 8. As before, the motion (M) and detail (D) algorithms take information from the nearest temporally and vertically accurate lines, respectively. The detail algorithm eliminates twitter but has poor motion portrayal, as for 625/100, 2:1. The motion algorithm, as for 625/100, 2:1, preserves twitter, but does not display combing since there is no interlace. Using the motion algorithm, conditions which produce combing at 625/100, 2:1 produce fringing at 625/100, 1:1, which is marginally less visible, and motion portrayal is generally good.

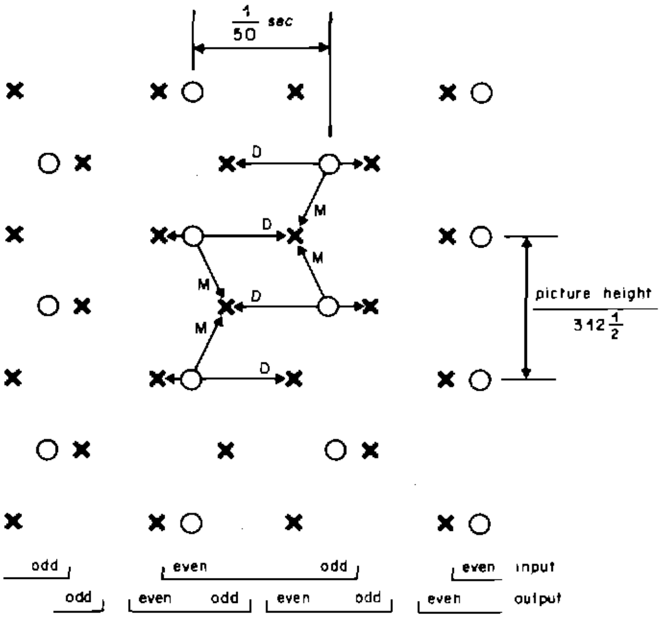


Fig. 6 – 625/100 2:1 structure and algorithms.

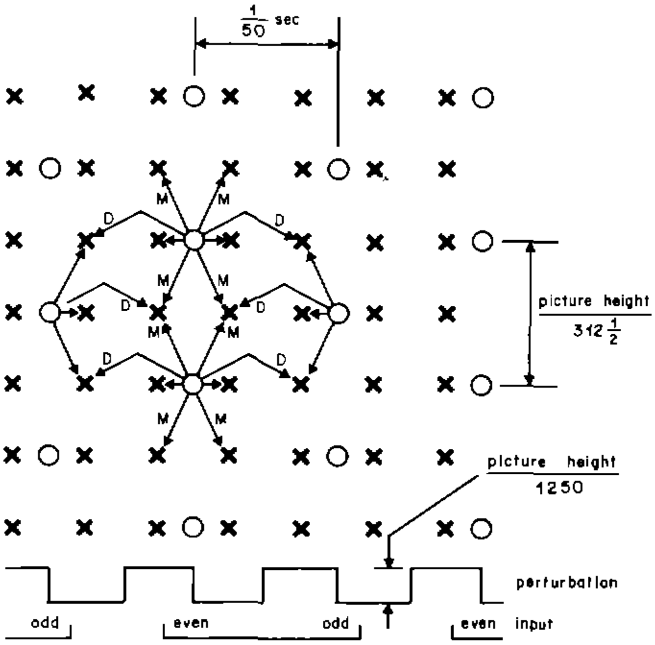


Fig. 8 – 625/100 1:1 structure and algorithms.

4.4. 1250/100, 2:1 interpolated

As for 625/100, 1:1 the line and field scanning rates must be raised to 62, 500 Hz and 100 Hz, respectively and the video bandwidth raised to 22 MHz.

Again, large area flicker is removed, the structure visibility is greatly reduced and line crawl is made less visible, despite its lowest rate being the conventional 11.5 seconds per picture height, since a 625-line structure is seen when crawl occurs. Interline twitter may be eliminated by the interpolation process.

The structure and algorithms for 1250/100, 2:1 are shown in Fig. 9. By comparing Figs. 8 and 9 it can be seen that 1250/100, 2:1 is merely a 50 Hz perturbed version of 625/100, 1:1. The algorithms used are the same as for 625/100, 1:1. The detail algorithm eliminates twitter but gives a motion judder, while the motion algorithm preserves twitter at 25 Hz with combing and fringing on moving vertical edges. However, here the combing is at 625-lines instead of the 312½ lines produced by combing in the 625/100, 2:1 structure, and is much less visible.

4.5. 1250/100, 4:1 interlaced

This structure is obtained by simultaneously doubling the line and field scanning frequencies to 31,250 Hz and 100 Hz respectively, and by doubling the video bandwidth to 11 MHz.

There are many possible versions of a 4:1 interlaced structure, the most promising class of which has a 'scrambled' format a simple version of a scrambled structure is depicted in Fig. 10.

Large area flicker is eliminated and twitter can be reduced, but structure visibility is not greatly diminished because 4:1 interlaced structures are beset by a general restlessness and proneness to line crawl. Although 4:1 interlace appears to offer an economic way of obtaining a 1250-line raster, in general, 1250 lines are seldom seen as the overall impression is dominated by 312½- and 625-line crawl. The lowest crawl rate is 11.5 seconds per picture height. Also, perfect 4:1 interlace is quite difficult to achieve with the techniques used in this work.

The structure and universal algorithm for the scrambled structure (A) shown in Fig. 10 can be seen to progress alternately upwards and downwards. Thus the dominant line crawl is avoided, but interline twitter remains; motion portrayal is good.

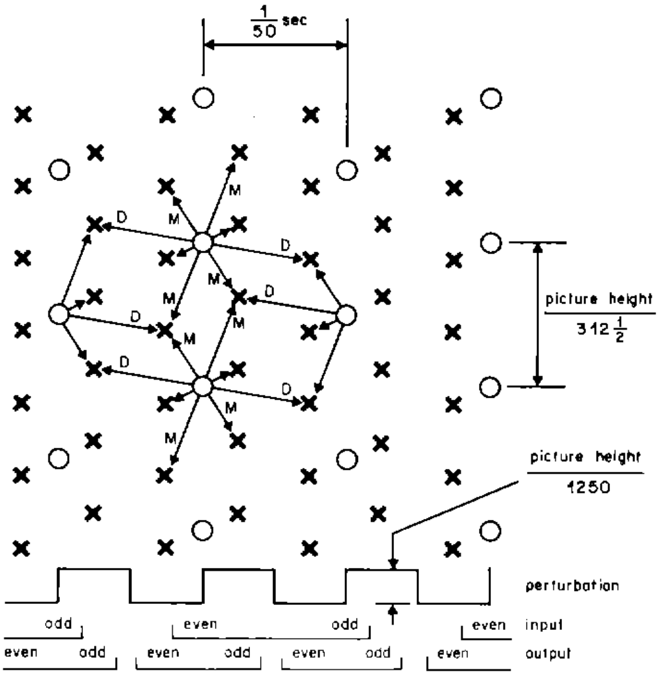


Fig. 9 – 1250/100 2:1 structure and algorithms.

The structure and algorithms for a different scrambled structure (B) are shown in Fig. 11. By comparison with Fig. 6 it can be seen that this is simply a 625/100, 2:1 structure with alternate output pictures shifted so as to interlace with each other. The algorithms used are the same as for 625/100, 2:1. The detail algorithm ameliorates twitter and has motion judder, while the motion algorithm gives good motion portrayal but

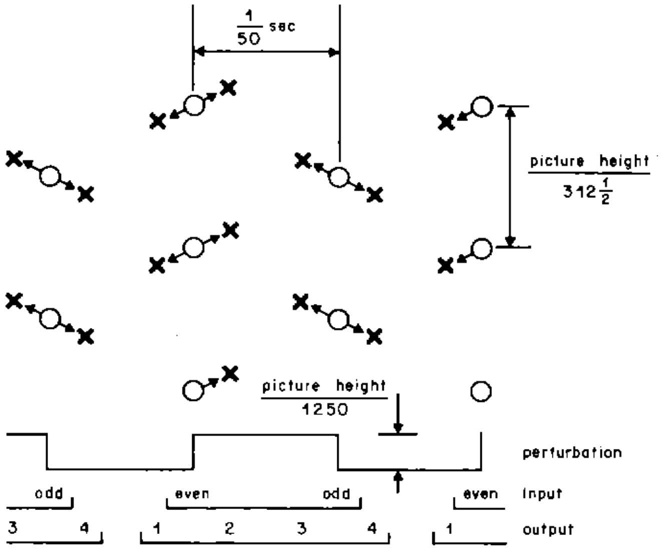


Fig. 10 – 1250/100 4:1 'Scrambled (A)' structure and algorithm.

preserves twitter. The detail algorithm does not eliminate twitter because the structure itself has a 25 Hz periodic vertical motion which is easily confused with twitter.

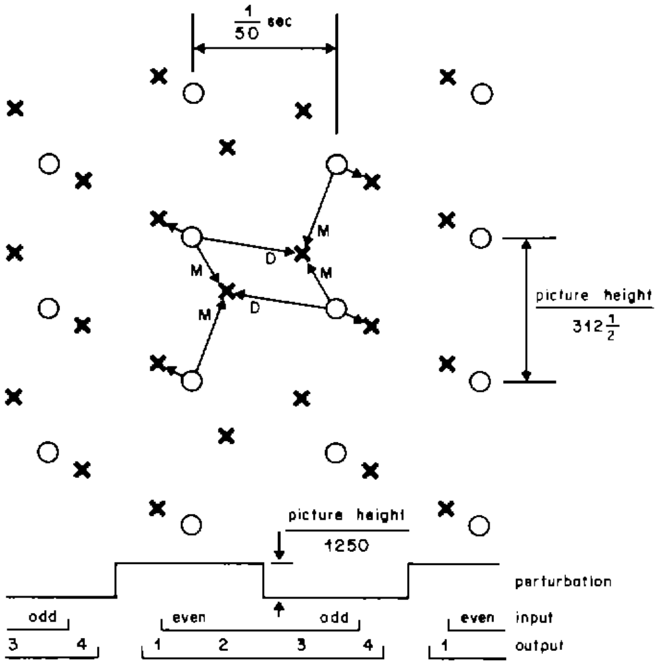


Fig. 11 – 1250/100 4:1 'Scrambled (B)' structure and algorithms.

Generally the 4:1 structures do not perform well although they are inexpensive to implement. The overall impression is of a restless structure which was not liked in the subjective tests.

4.6. 625/100, 2+2:1 interlaced

This structure is obtained by simultaneously doubling the line and field scanning frequencies to 31,250 Hz and 100 Hz respectively and by doubling the video bandwidth to 11 MHz; an experimental examination of this structure has been reported by Kraus[4]. It is really a 4:1 interlaced structure, as four fields are required to make one complete picture. The output display is in the sequence even, even, odd, odd, with appropriate vertical shifts in the raster.

Large area flicker is eliminated but interline twitter and line crawl are both largely unaffected. The greatest merit of this scanning structure, other than the elimination of flicker, is that it is very simple to achieve, involving no interpolation at all.

The 625/100, 2+2:1 structure is simply a temporally line-repeated version of the input 625/50 signal without interpolation and it is, therefore, no surprise that motion portrayal is good but twitter remains.

4.7. 625/50, 1:1 interlaced (sequential)

This structure is obtained by doubling the line scanning frequency to 31,250 Hz; the display bandwidth is also doubled to 11 MHz.

Large area brightness flicker is unaffected, interline twitter can be cured with careful choice of interpolation, line crawl is eliminated, and the line structure may be less visible since the lack of interlace produces a restful raster. The structure and algorithms are very similar to those for 625/100, 1:1 shown in Fig. 8; in the detail algorithm the extra lines are copied from those with the same vertical position in the nearest field, and in the motion algorithm the extra lines are the average of the spatially nearest lines in the temporally nearest field.

The detail algorithm eliminates twitter but imparts motion judder. The motion algorithm preserves twitter at 312½ cycles per picture height and introduces some twitter at 156¼ cycles per picture height, since because they are averaged, alternate lines of each field have a zero-response at 156¼ cycles per picture height, but motion portrayal is perfect.

4.8. 1250/50, 2:1 interlaced

As for 625/50, 1:1, the line scanning frequency and video bandwidth must both be doubled to 31,250 Hz and 11 MHz respectively.

Large area brightness flicker is unaffected, but structure visibility is greatly reduced and line crawl is much less visible, despite its lowest rate being 23 seconds per picture height, because the crawling structure has 625 lines. The interline twitter frequency remains at 25 Hz but twitter can be virtually eliminated by the interpolation process.

The structure and algorithms of 1250/50 2:1 are very similar to those of 1250/100, 2:1 shown in Fig. 9. They are basically the structure and algorithms of 625/50, 1:1 with alternate output fields moved vertically by ± (picture height)/2500. Therefore, the performance of the structure is very similar to that of 625/50, 1:1.

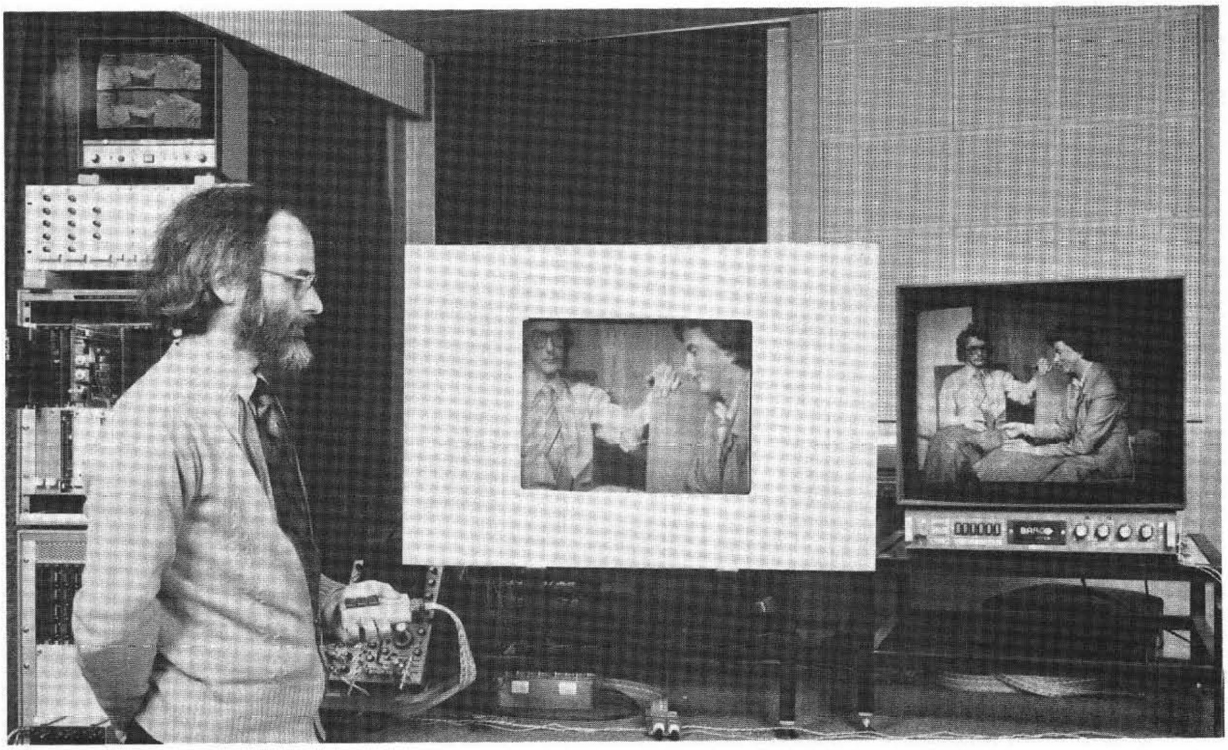


Fig. 12 – The equipment.

5. Subjective tests

5.1. Scanning structure tests

A series of subjective tests was carried out to assess the merits of the scanning structures, using a peak screen brightness of 90 cd/m^2 (26 foot lamberts). Enlarged pictures were used, as described in Section 4.1. and the equipment was arranged to provide, as a reference, the 625/50, 2:1 standard by omitting alternate fields in a 1250/100, 4:1 structure.

Fourteen observers were used in two test sessions, seated at between 5 and 8 times actual picture height, equivalent to between 2.5 and 4 times the enlarged picture height. Figure 12 shows the equipment in use with a grey card surrounding the ouput monitor used in the tests to suggest the dimensions of a complete 'enlarged' picture; the monitor showing the full picture (at normal size) was not used in these tests. All of the structures described in Section 4 were tested, except for the 1250/100, 4:1 scrambled A structure, as the scrambled B structure adequately represented that type of structure.

Pictures were assessed for large-area flicker, interline twitter, line-structure visibility, and line crawl. The pictures used in the tests were:-

Plain field, 100% peak white (0.7V).

EBU test slide 'Young Couple' normally used for assessment of cross-colour and effects of interlace, shown enlarged in Fig. 13.

Moving pictures, film taken of steam trains involving horizontal and vertical motion; a still photograph from the film is shown in Fig. 14.

The first subjective test was for large-area flicker using the plain field of peak white. The second test using the 'Young Couple' slide was for interline twitter and line-structure visibility. Line crawl was assessed in the third test using the trains film. The CCIR rec. 500 five-point impairment scale was used, as shown in Table II. The results are shown in Fig. 15.

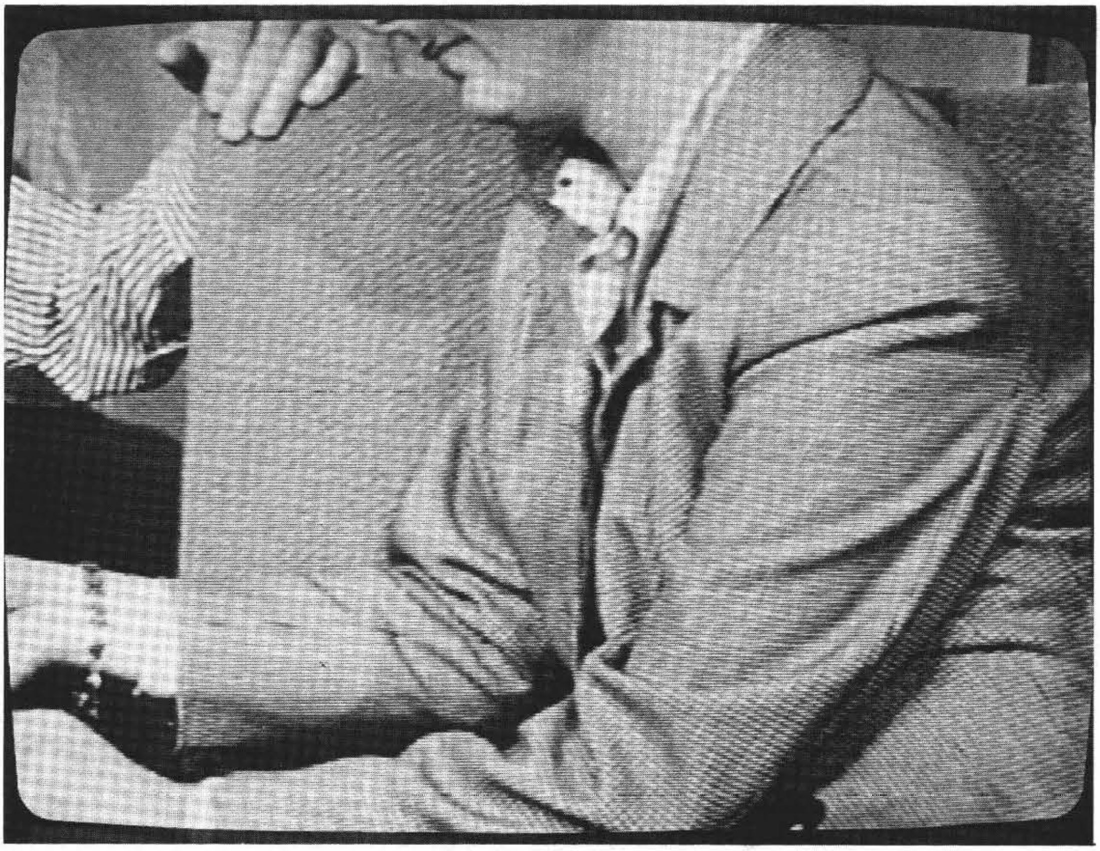


Fig. 13 — 'Young Couple' slide, shown enlarged at 625 lines.

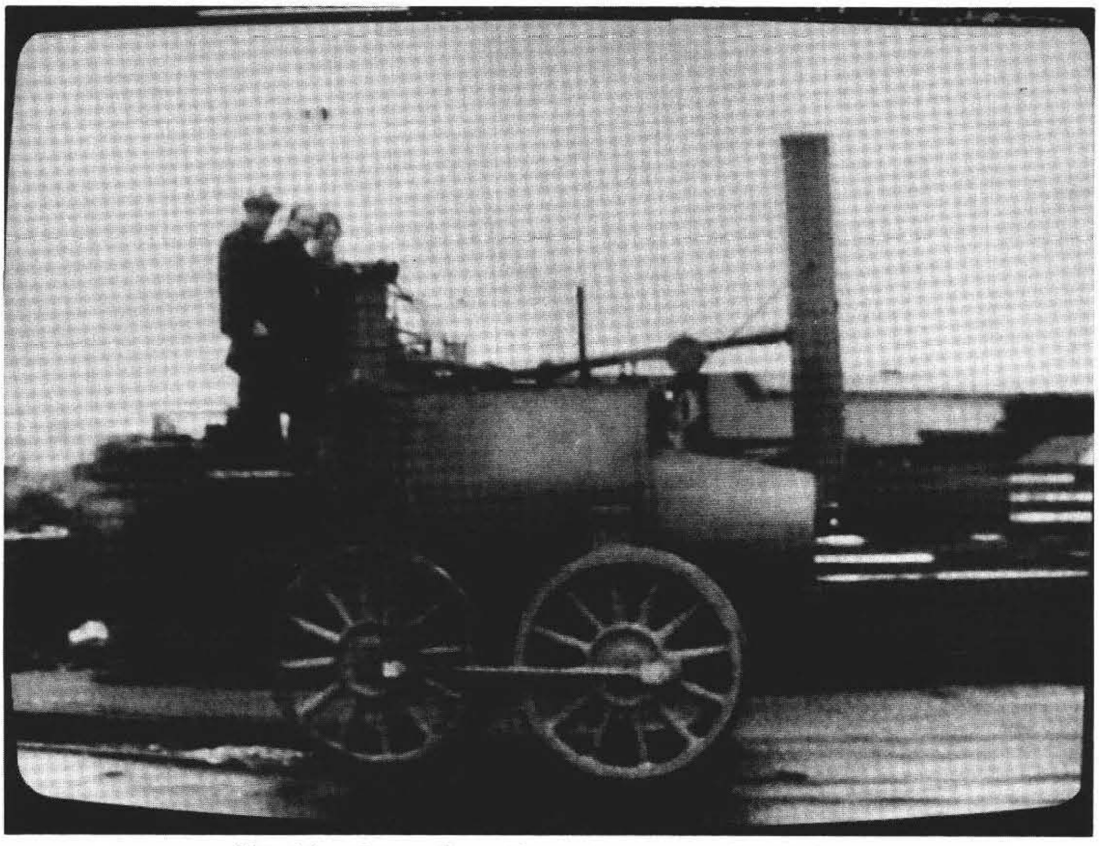
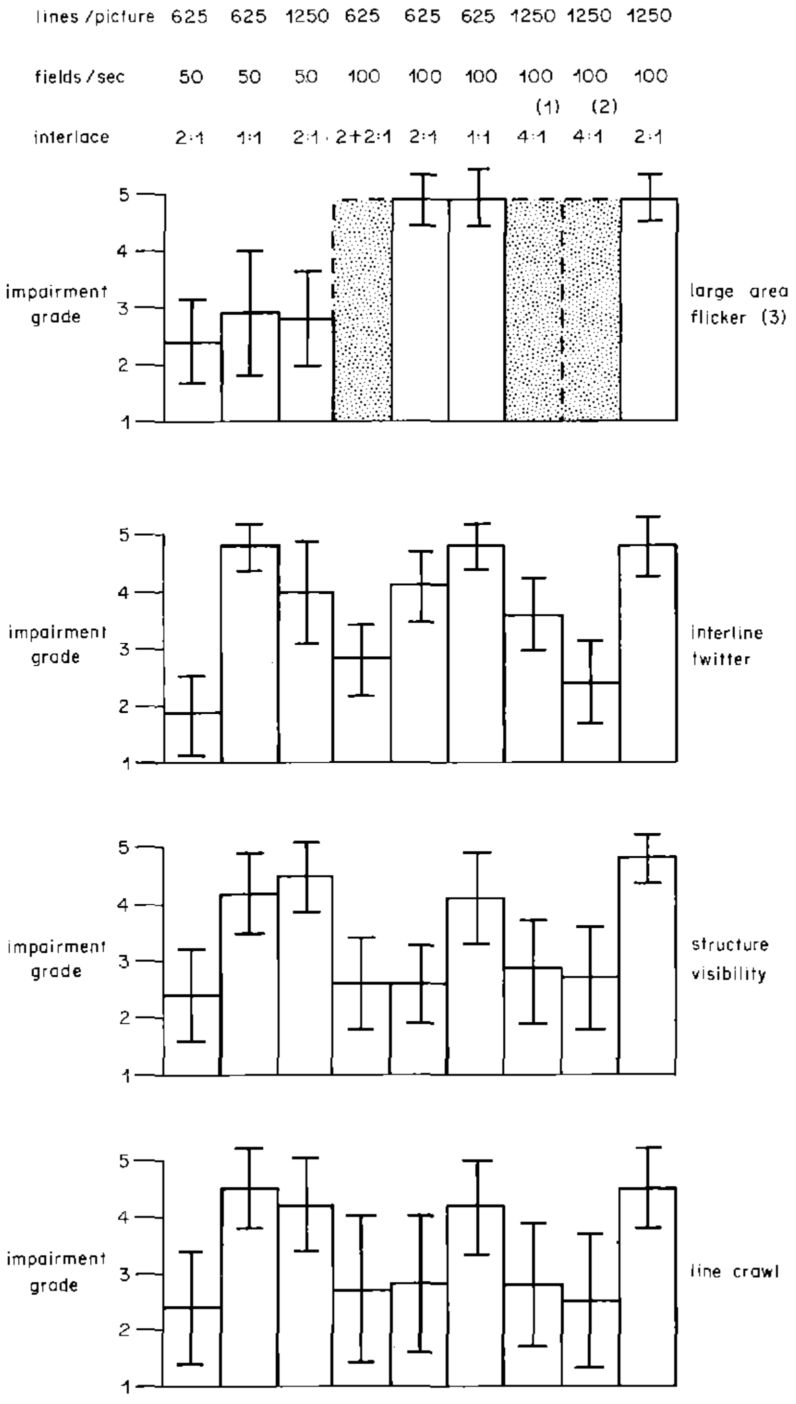


Fig. 14 — Scene from the test sequence 'Trains'.



(1) scrambled structure

(2) progressive structure

(3) shaded results were assumed and not measured

Fig. 15 – Results of subjective tests on scanning standards.

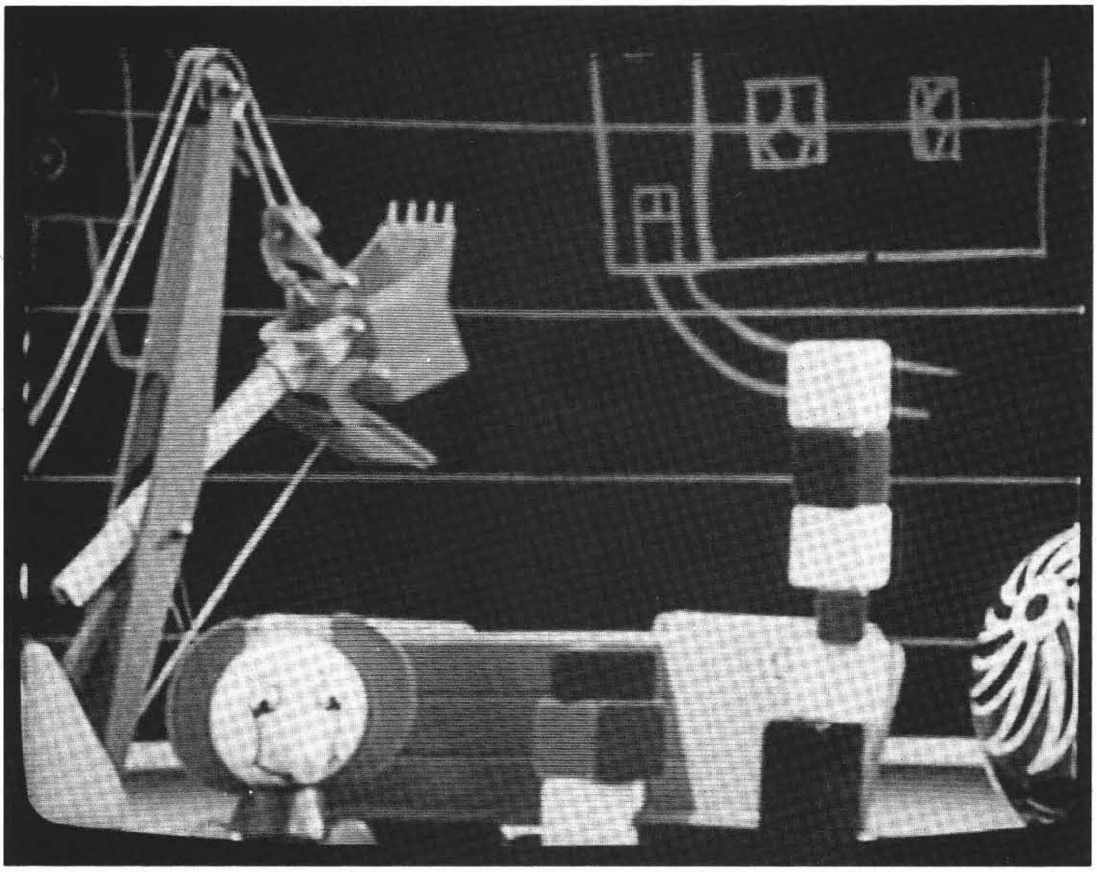


Fig. 16 – 'Blackboard' slide.

TABLE II

CCIR Impairment Scale

5 Imperceptible

4 Perceptible, but not annoying

3 Slightly annoying

2 Annoying

1 Very annoying

The test results show that a 100 Hz field rate is a complete cure for large-area flicker, regardless of the actual structure. It was felt to be adequate to test only three of the 100 Hz structures described above.

The twitter test results indicated that sequential (1:1) or 1250-line, 2:1 interlace structures are good, with 625/100, 2:1 also acceptable. The low grading for the 625/100, 2+2:1 and the 1250/100, 4:1 structures was not surprising, but it was better than that for conventional 625/50, 2:1.

The line-structure visibility test results clearly indicated that sequential or 1250-line, 2:1 structures are preferable over all the others. This result is interesting in that it shows little difference between the 625-line sequential and the 1250-line, 2:1 structures. This must arise from the general restfulness of the sequential structures.

The line crawl test produced large standard deviations because some observers had difficulty in identifying line crawl even after the effect had been demonstrated. This perhaps indicates that crawl can be ignored by some observers. However, the results show a definite preference for the sequential and 1250-line, 2:1 structures.

5.2. Screen size tests

A limited number of tests were carried out to compare the enlarged picture quality using the conventional 625/50, 2:1 standard, with a normal size of picture; two identical monitors were used side by side. Observers were asked to assess monochrome pictures for interline twitter, noise and grain visibility, cross-luminance (PAL coded signals were used with a chrominance notch filter in the apparatus to remove the subcarrier), the effects of ringing on edges, film steadiness, and sharpness. Five source materials were used:-

Good quality broadcast film, with minimal grain but with ringing caused by a detuned receiver.

Outside broadcast from a circus, with noise near black, some ringing and poor resolution.

Old film, black and white with large grain, fairly soft and unsteady.

Slide 'Young Couple' as used for the first scanning structure tests; sharp with cross luminance and twitter.

EBU test slide 'Blackboard', sharp with cross-luminance and twitter, shown in Fig. 16.

The observers were asked to mark each picture in absolute terms for each of the defects that they could see, using the five-point impairment scale. For each named defect the enlarged picture was marked as worse than the normal size picture. The difference in impairment grade for the two screen sizes is shown in Figure 17. They indicate that each defect, if visible at all, is between 1 and 1.5 grades worse for the enlarged picture. This is a measure of the problems that may be encountered when large, bright, flare-free displays are available for domestic use. The results for film steadiness should be used with caution, as different results may be obtained if 100% of the enlarged picture area is visible (25% was shown in all of the tests, for the instrumental reasons given earlier).

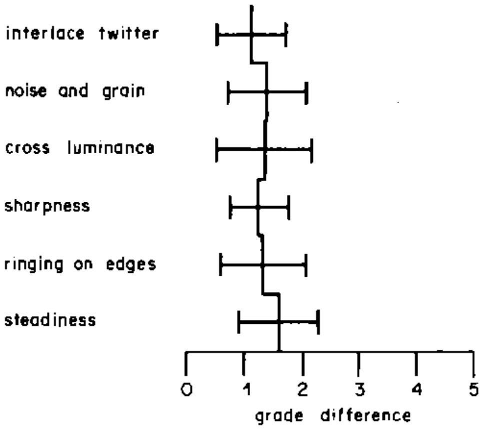


Fig. 17 – Results of picture enlargement tests.

5.3. Source standard tests

The opportunity was taken to compare the subjective sharpness of a conventional 625-line source structure with that of a simulated 1250-line source structure. Since the observers were accustomed to seeing enlarged pictures, comparisons were made between a picture enlarged electronically and a picture enlarged photographically. Both resultant enlargements were 25% of the 'Young Couple' slide. For the simulated 1250-line source condition, provided by photographic enlargement before source scanning, the electronic enlargement was switched off and the slide was displayed at 625/100, 2:1 with the detail algorithm shown in Fig. 2, so that a 2 to 1 enlargement was available for each condition.

The observers were asked to mark on the five point quality scale, shown in Table III, marking only the relative sharpness of three conditions:-

625/50, 2:1 source: 625/100, 2:1 display

625/50, 2:1 source: 1250/100, 2:1 display as shown in Figure 18.

'1250' source: 1250/100, 2:1 display, shown in Figure 19.

TABLE III

CCIR Quality Scale

5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

All the pictures were displayed at 100 Hz field rate to avoid interlace twitter and large area brightness flicker. Only a limited number of tests were conducted, and the results should *not* be compared with the earlier impairment tests, all of which used a 625-line source; those tests were marked on an impairment scale and were not marked for sharpness or overall quality.

The results are shown in Fig. 20. Clearly the simulated 1250-line sourced picture was much sharper than either of the 625-line sourced pictures. The up-converted 625-to-1250-line

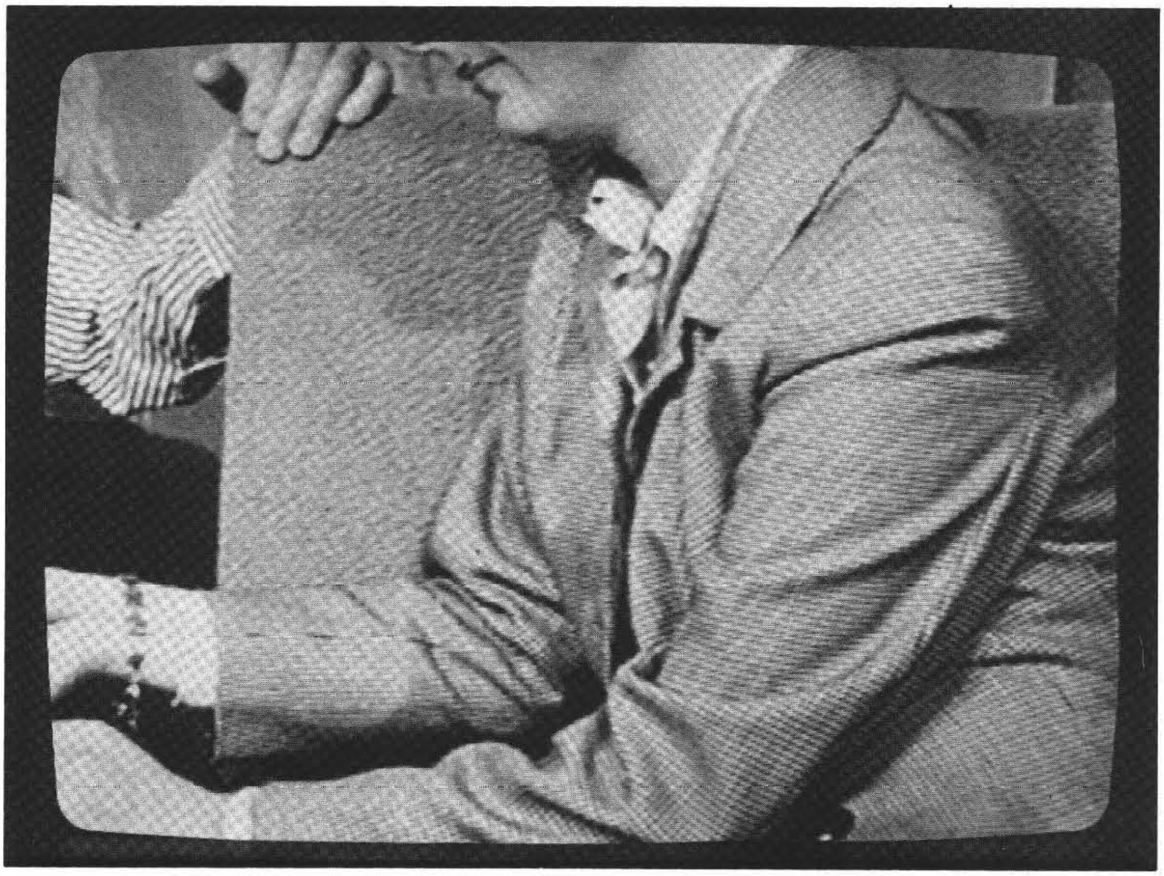


Fig. 18 – 'Young Couple' slide, 625 source, 1250 display.

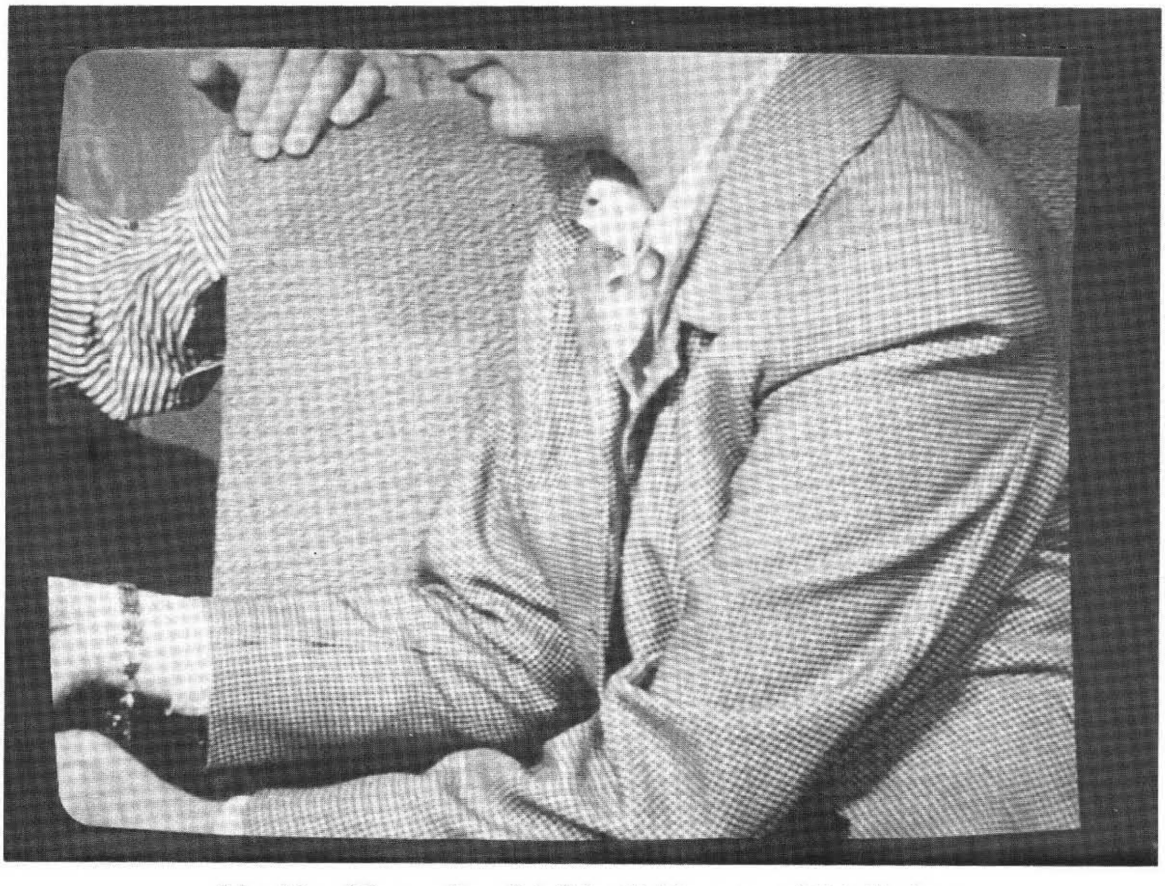


Fig. 19 – 'Young Couple' slide, 1250 source, 1250 display.

picture was found to be not much sharper than the 625-line picture. A greater improvement could probably be obtained if a more complex interpolation algorithm were to be used, since the line broadening used in the algorithm actually visually attenuates high vertical frequencies. However, the most significant improvement would probably be obtained if the transmitted 625-line signal was derived from a suitably down converted and filtered 1250-line source signal. It remains to be seen how far such improvements could take the image towards the quality achieved by a true 1250-to-1250 system.

6. Future work

In view of the results of the subjective tests, work on 1250/100, 4:1 has stopped, since it offers no significant advantage over 625/100, 2:1 and the interlacing of the structure is difficult to achieve accurately.

Work on other structures will continue, using enlarged pictures. Full sized pictures of 1250/100, 2:1 cannot readily be displayed on any monitor available at present but a display device of adequate performance may, however, become available in the future and such a structure could form the basis of a true high definition standard compatible with the existing 625/50, 2:1 standard.

It has been concluded that there is no compromise algorithm suitable for both the adequate portrayal of motion and the preservation of all vertical detail. However, detail can be preserved with a detail algorithm, and motion portrayal with a motion algorithm. Thus, an interpolator which could adapt within the picture between these extremes, under the control of a motion detector, could provide an acceptable display. Alternatively, more complex algorithms using more than one line-delay might ameliorate the resolution loss incurred with the motion algorithm. Variable interpolation is simple to achieve, the greater problem being a completely satisfactory motion detector. For example, a motion detector could be constructed using a temporal difference signal D_T and a spatial difference signal D_S as shown in Fig. 21[5]. This requires four access points to the information, two from either end of a picture delay (A and B in Fig. 21) and two one field-line apart (C and D in Fig. 21). By forming the ratio $\frac{D_T - D_S}{D_T + D_S}$ a control signal can be derived which varies from +1 for pure motion to −1 for pure stationary vertical detail. It is independent of the amplitudes of motion and detail and is fairly immune to noise. A signal derived from a detector based on this principal is now being used to control an adaptive interpolator and the results are very encouraging.

Extension of the equipment to colour operation is also planned; new equipment, microprocessor-controlled and using 64 k RAMs is being built.

A larger, brighter display with good resolution and low flare would greatly help in this work, but such a display is not readily available. A laser projector system may prove to be adequate for research purposes, and will be investigated.

7. Conclusions

It has been shown that some of the defects of the conventional display of 625/50, 2:1 signals can be eliminated or ameliorated by raising the line and/or field scanning rates and applying suitable interpolation algorithms.

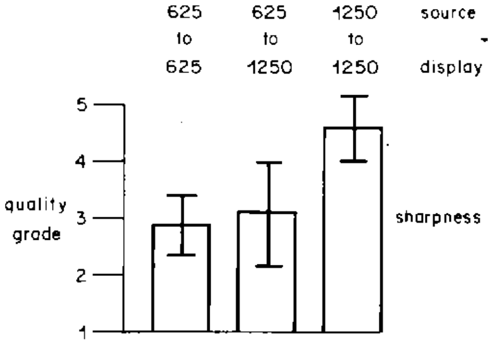


Fig. 20 – Results of source standard tests.

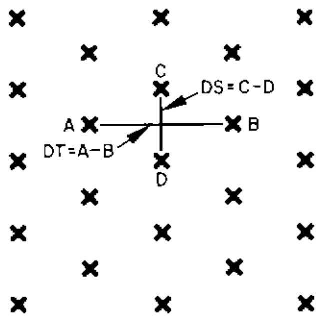


Fig. 21 – *Temporal and spatial difference signals in a 2:1 interlaced structure.*

The two most promising structures that were investigated experimentally were 1250/100, 2:1 and 625/100, 1:1 (sequential). Large area flicker is eliminated, line crawl is rendered less visible, interline twitter caused by interlace is potentially eliminated depending on the interpolation algorithm used, and the static line structure is less objectionable. These are all desirable features for large, bright displays.

The problems of adequate motion portrayal have not been solved and along with colour operation and higher definition considerations, they will be the subjects of future work. Adaptive interpolation using a motion detector is likely to provide a solution.

Ultimately a scanning standard of 1250/100, 2:1 could provide a very good display of not only 625/50, 2:1 input signals but also high definition source signals generated on a 1250/100, 2:1 standard and passed through a 625/50, 2:1 transmission channel.

8. Acknowledgements

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9. References

1. FUJIO, T., ISHIDA, J., KOMOTO, T., *and* NISHIZAWA, T. 1979. High definition television system – signal standard and transmission. NHK Laboratories Note No. 239, August 1979.
2. WENTWORTH, JOHN W. Colour Television Engineering, 1955. McGraw-Hill, pp. 51–53.
3. Principles of colour television, Chapter 7 'Additional properties of the eye'. Hazeltine Corporation Report No. 7142. April 27, 1953, Little Neck, New York.
4. KRAUS, U.E., 1981. Avoidance of Large-Area Flicker in Home TV Receivers. Rundfunktechniscke Mitteilungen, 25, pp. 264–269, November/December 1981.
5. UK Patent Specification No. 7915828, Improvements to Television Display, 8 May 1979, pp. 5–6.

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